

The Flow of the River Thames in Relation to British Pressure and Rainfall Changes

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When the explosion takes place in a long vessel, wave action is frequently set up. A non-uniform distribution of the explosive enhances this phenomenon. The velocity of the pressure-wave is measured and compared with the velocity of sound under similar conditions. Generally speaking the work confirms the remarkable properties of cordite with regard to its high power and to the regularity of the effects produced.

The paper is accompanied by some 20 figures illustrating the results obtained, and is followed by tables giving the principal numerical values.

The Flow of the River Thames in Relation to British Pressure and Rainfall Changes.

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[PLATES 6 AND 7.]

In a previous communication* to the Society we gave the results of a preliminary survey of the behaviour of the short-period barometric variation over many areas on the earth's surface. The very close association of rainfall with pressure has led to an enquiry into the variation of the former in relation to this latter change; this investigation is still in progress.

The recent publication, July 18, 1904, of a memorandum to the Thames Conservators on the "Rainfall and Floods in the Basin of the River Thames above Teddington Weir" since the year 1883, and a previous report on "The Shrinkage of the Thames and Lea," published by the London County Council in 1903, present data the discussion of which, although belonging to the general investigation to which reference has just been made, forms rather a subject for special enquiry and makes a reference to it desirable at the present time.

The present communication is, then, strictly limited to these and other data which have been collected in Britain. The relation to the questions of rainfall and pressure changes over large areas is, however, discussed. Reference to the Lea has here been omitted, since this river has been stated in the above-mentioned report of the L.C.C. to exhibit variations similar to those of the Thames.

* 'Roy. Soc. Proc.,' vol. 73, p. 457.

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Among the flood statistics given in the memorandum are tables showing the total quantity of water flowing over Teddington Weir, with the addition of the water abstracted by the Water Companies. These tables are three in number, and give the flow for the whole year and for the summer (April and September) and winter (October to March) months from 1883 to 1903. Similar tables are also inserted showing the average rainfall, for the same period, at 12 stations in the basin of the River Thames above Teddington.

In the present discussion the year has been divided according to the mean annual variation curves of the phenomena dealt with. In the case of rainfall for the British Isles, the 12 months from April 1 to March 31 of the following year have been employed (*see* fig. 1). April being the month when the rainfall is at about a minimum, this month, together with the 11 months following, thus include a complete rainfall cycle.

In the curves for rainfall—and the same holds good for those of pressure—the mean yearly values are plotted in September of each year; thus the point inserted for the year 1884 represents the mean value for the period April 1, 1884, to March 31, 1885.

For the river data a different grouping of the months is employed. This was necessary since the flow followed the rain instead of being synchronous with it. This apparent “lag” of the river’s response to the rainfall is shown also in the accompanying figure (fig. 1), and it will be seen that the minimum or maximum flow values are *five months after* those of rainfall.

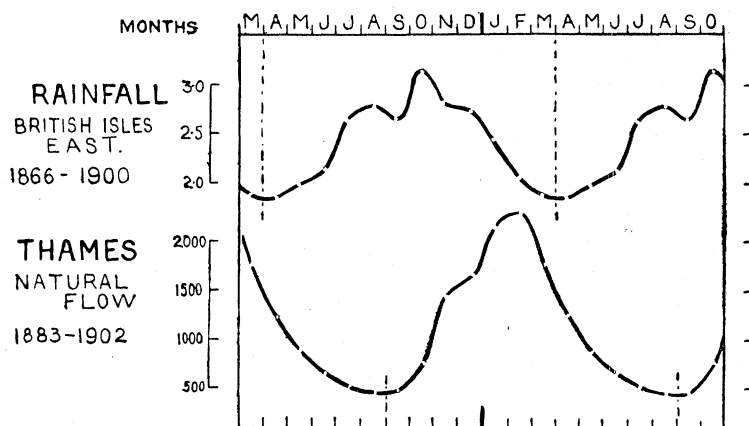


FIG. 1.—Curves to illustrate the relation between the mean annual Variation of Rainfall for the British Isles and the mean annual Variation of the Flow of the River Thames.

For the river data, then, the year has been taken to commence in the beginning of September and end on the last day of August of the following year. The centre of the period being the month of February, each yearly

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value might have been plotted in this month, but it has been placed under that of the rainfall corresponding to this flow—*i.e.*, under September of the preceding year. Thus the rainfall from April, 1903, to March, 1904, which is the last point plotted on the curves in Plate 6, is placed vertically over the point representing the river flow as measured between September, 1903, and August, 1904. (*See* Plate 6, Curves III and IV.)

The accompanying table (Table I) gives the data published by the Thames Conservancy computed on the above scheme, and these values put in the form of curves in Plate 6 (Curves III and IV) and indicated by continuous lines.

Table I.—Natural Flow at Teddington Weir compared with the Average Rainfall of Twelve Stations in the Thames Valley.

Year.	Natural flow in millions of gallons. Sept.—Aug.	Actual rainfall in inches. Apr.—Mar.	Year.	Natural flow in millions of gallons. Sept.—Aug.	Actual rainfall in inches. Apr.—Mar.
1882-3 ...	(817,492)*		1893-4.....	323,938	22·7
1883-4 ...	459,035	26·5	1894-5.....	665,770	31·0
1884-5 ...	328,899	23·7	1895-6.....	329,922	26·0
1885-6 ...	563,333	28·1	1896-7.....	645,548	30·4
1886-7 ...	521,042	29·9	1897-8.....	277,159	22·0
1887-8 ...	371,635	22·2	1898-9.....	392,499	25·7
1888-9 ...	542,673	28·1	1899-1900	450,159	27·5
1889-90...	341,527	25·4	1900-1.....	334,685	24·3
1890-1 ...	226,771	21·7	1901-2.....	232,249	23·0
1891-2 ...	595,905	32·1	1902-3.....	520,766	27·0
1892-3 ...	450,247	26·3	1903-4.....	851,605	41·7
Total, 1883-1904.....				9,425,367	565·3
Average, 1883-1904.....				448,827	27·0

In order to deal with as long a period as possible, an attempt has been made to determine the flow for years previous to 1883. By the kindness of the Conservators of the River Thames, to whom application was made for any available data, permission was given to abstract valuable information existing in their archives. This afforded a means of obtaining a good general idea of the behaviour of the river from March 1, 1859.

This record is given in the form of daily readings in feet and inches of the level of the river at the Lower Sill at Teddington. Monthly means of these

* This value is obtained by adding the flow computed from the height of the river observed during September to December, 1882, to the actual flow measured during January to August, 1883. (*See* also Table II.)

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values were then formed, and finally, annual means for the 12 months beginning in September and ending the following August; these annual means from 1860–1883 were then put in the form of a curve. This curve indicated a prominent short-period variation of about three years, and there was a general tendency of the curve as a whole to give readings of less height on the average year by year. Such a gradual change, since the zero of the sill remained constant, could only be due either to a long-period variation in the supply of water to the river at the sill or to the result of the lowering of the river bed by dredging or natural causes. The only information with regard to the latter that could be obtained was that, previous to 1879, dredging had been in progress, but to what extent was unknown.

It was, therefore, thought advisable to look upon this gradual apparent lowering of the water surface as due to dredging, and therefore eliminate it. The amount was, however, small, namely 8 inches in 23 years, and consequently had little effect on the resulting values of the sill readings. This was accomplished in the final step of converting the sill readings into flow. The method of reduction was to use the relationship between the depth of the lower sill (DLS) and the flow in millions of gallons per day which the Conservators had found to exist and had utilised since 1883.

The formula

$$(\text{DLS} - 5 \text{ feet } 3 \text{ inches})^2 \cdot 40 \cdot 35$$

represents the flow in millions of gallons per day, where DLS is the reading of the depth of the lower sill and the two other numbers constants for the year 1883.

In the reduction of the mean yearly values of the sill readings allowance was made for this apparent lowering of the water level between 1860 and 1883, and the resulting values of flow for each year are given in the third column of Table II; the second column shows the corresponding sill readings. The above values have been put in the form of a curve (Plate 6, Curve III, broken line portion).

In the above figures and curves no allowance has been made for the water abstracted by the Water Companies. This, however, does not materially affect the values as the quantity is relatively small. Further it would only make the curve for this period, 1860–1883, higher than it is at present.

Since 1883 the water abstracted by the companies has risen from 30 to 50 thousand millions of gallons per year, and as the mean value of flow in the same period is 412 thousand million gallons, this means that the withdrawal has risen from 7 to 12 per cent.

It is fair to assume, therefore, that less than 30 thousands of millions of gallons were extracted annually before 1883. If we take 20 thousands of

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Table II.—Height and Computed Flow of the Thames at Teddington compared with the Average Rainfall of “England South.”

Year.	Height in feet and inches. Sept.—Aug.	Computed flow in 1000 million gallons. Sept.—Aug.	Rainfall in inches. Apr.—Mar.	Year.	Height in feet and inches. Sept.—Aug.	Computed flow in 1000 million gallons. Sept.—Aug.	Rainfall in inches. Apr.—Mar.
1859–60	ft. in. 13 1	758		1871–2	ft. in. 12 3	658	32·7
1860–1	13 5	826		1872–3	13 1	835	40·0
1861–2	12 9	698		1873–4	11 5	511	22·5
1862–3	12 0	562		1874–5	12 2	658	28·9
1863–4	12 3	607		1875–6	12 10	802	34·1
1864–5	12 4	634		1876–7	12 9	790	36·9
1865–6	12 11	752		1877–8	11 8	580	29·5
1866–7	13 1*	797*	31·5	1878–9	12 11	836	32·4
1867–8	11 11	577	27·7	1879–80	11 6	562	28·7
1868–9	12 9	736	31·7	1880–1	12 4	730	34·5
1869–70	11 11	589	27·1	1881–2	11 4	542	25·5
1870–1	11 5	496	22·8	1882–3	(12 9)	(817†)	35·2
Total, 1867–1882.....				182 3	9902	455·0	
Average, 1867–1882.....				12 2	660	30·3	

millions of gallons as a possible mean annual value abstracted during the period 1867–1883, then, since the mean computed flow for this period amounts to 660 thousands of millions of gallons, only about 3 per cent. of the flow was utilised. Such a quantity becomes practically negligible and can, therefore, be left out of consideration.

Having thus secured a more or less homogeneous series of observations from the Teddington gauge, an attempt was made to check the curve thus obtained by the readings of another gauge in a different part of the river. With this intention inquiries made at the Thames Conservancy Offices, led us to communicate with Mr. Brough Taylor, who informed us that his late father, as Chief Engineer of the Lambeth Water Works, made a series of gaugings, commencing in 1860, of the Thames at Ditton. A request to the present engineer of the Metropolitan Water Board, Mr. Thomas F. Parkes, for information on this subject, resulted in the loan of books containing records of the daily heights of the river at Surbiton from June, 1863, to December, 1904.

* There being no record of the height during June, July, August, and September, in 1866, the means of the heights recorded during these four months in the four preceding and the four following years have been used.

† See note to Table I.

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We take this opportunity of returning our thanks to those mentioned above for their willing assistance.

The treatment of these data was the same as that adopted for the Teddington gauge readings. The monthly means were first formed from the daily readings, and then the mean values of the months from September to August of the following year determined. In this way a series of mean annual values of the level of the river at Surbiton was obtained, but it was found impossible to convert this into flow, as the necessary data were not available; further, for the same reason, no allowance has been made for the water abstracted by the water companies. The following table contains the values thus employed:—

Height of the Thames in Relation to “Mean Summer Level” at Surbiton.

Year. Sept.—Aug.	Height in feet.	Year. Sept.—Aug.	Height in feet.	Year. Sept.—Aug.	Height in feet.
1863-4	+0·17	1877-8	+1·11	1891-2	+1·08
1864-5	+0·18	1878-9	+1·81	1892-3	+0·67
1865-6	+1·22	1879-80.....	+0·85	1893-4	+0·44
1866-7	+1·29	1880-1	+1·54	1894-5	+1·05
1867-8	+0·37	1881-2	+1·05	1895-6	+0·38
1868-9	+0·92	1882-3	+1·92	1896-7	+1·02
1869-70.....	+0·46	1883-4	+0·64	1897-8	+0·33
1870-1	-0·22	1884-5	+0·44	1898-9	+0·69
1871-2	+0·92	1885-6	+1·02	1899-1900...	+0·83
1872-3	+1·68	1886-7	+1·13	1900-1	+0·50
1873-4	+0·50	1887-8	+0·75	1901-2	+0·33
1874-5	+1·14	1888-9	+0·90	1902-3	+0·83
1875-6	+1·57	1889-90.....	+0·46	1903-4	+1·49
1876-7	+1·90	1890-1	+0·24		
				Total	35·90
				Mean.....	0·875

In Plate 6 (Curve II) these values are given, and it will be seen that the variations from year to year corroborate in a striking manner those indicated by the curve of the river flow at Teddington.

These two curves may then be taken to represent the changes from year to year (September to the following August) that the Thames undergoes in consequence of the variation in the supply of water to the river. In the memorandum to the Thames Conservators, to which reference has already been made, the very intimate relation which must necessarily exist between the rainfall of the basin and the river's discharge, was clearly pointed out for the period 1883 to 1903 (*see* Plate 6, Continuous Curves III and IV).

The rainfall curve employed in the memorandum represents only a comparatively small area of the British Isles, and only commenced in the year 1883.

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It happens, however, that these rainfall variations in the Thames valley are not restricted to this small region, but are found to be similar to those which occur over a very large area in the British Isles. To illustrate this, use may be made of the very complete rainfall data for the British Isles, collected and reduced at the Meteorological Office and published in their annual summaries. The United Kingdom is divided into 11 districts for meteorological purposes, and according to this arrangement the Thames basin would be included in those termed England South* and Midland Counties.

Curves for these two regions are given in Plate 6 (Curves V and VI), and a reference to them will show that they represent changes which are very similar and correspond in time with those given for the Thames basin. If many other districts be compared in the same way, a similar type of variation is apparent. Thus Plate 6, Curve VII, illustrates the rainfall variation for the combined districts of Scotland East, England East and North-East, the Midland Counties, and England South.

In fact, it may be said that the Thames basin rainfall is that of the whole of the South, Midland, East and North-East of England and Scotland East. The other districts in the British Isles (with the exception of Scotland North, which is different to all other districts in the British Isles) are of a type similar to each other, but present variations which, although not widely different from the Eastern and other districts, are sufficiently unlike them to be classified apart.

Since all the above series of rainfall statistics commence in the year 1866, we have a means of comparing the rainfall with the Thames flow for a much longer period than was attempted in the Memorandum previously mentioned. Making such a comparison by means of the curves in Plate 6 (Curves II to VII), not only do the variations in both curves indicate the close relationship between the rainfall over this extensive region and the flow or height of the River Thames, but the flow variation curve is thus shown to be of considerable accuracy.

It may, however, be pointed out that it does not seem necessary to collect and discuss the data over *the whole* of this region before any deduction for practical purposes can be made as to the flow of the Thames. The rainfall and barometric observations made at the Oxford Observatory (Radeliffe) exhibit variations from the year 1860 up to the present time so very similar to those of the Thames flow that the curves are very nearly interchangeable. So striking is the agreement that curves illustrating these

* *England, South*, comprises the counties of Dorset, Hampshire, Kent, Middlesex, Surrey, and Sussex. *Midland Counties* include Gloucester, Hereford, Leicester, Montgomery, Northampton, Nottingham, Oxford, Warwick, and York.

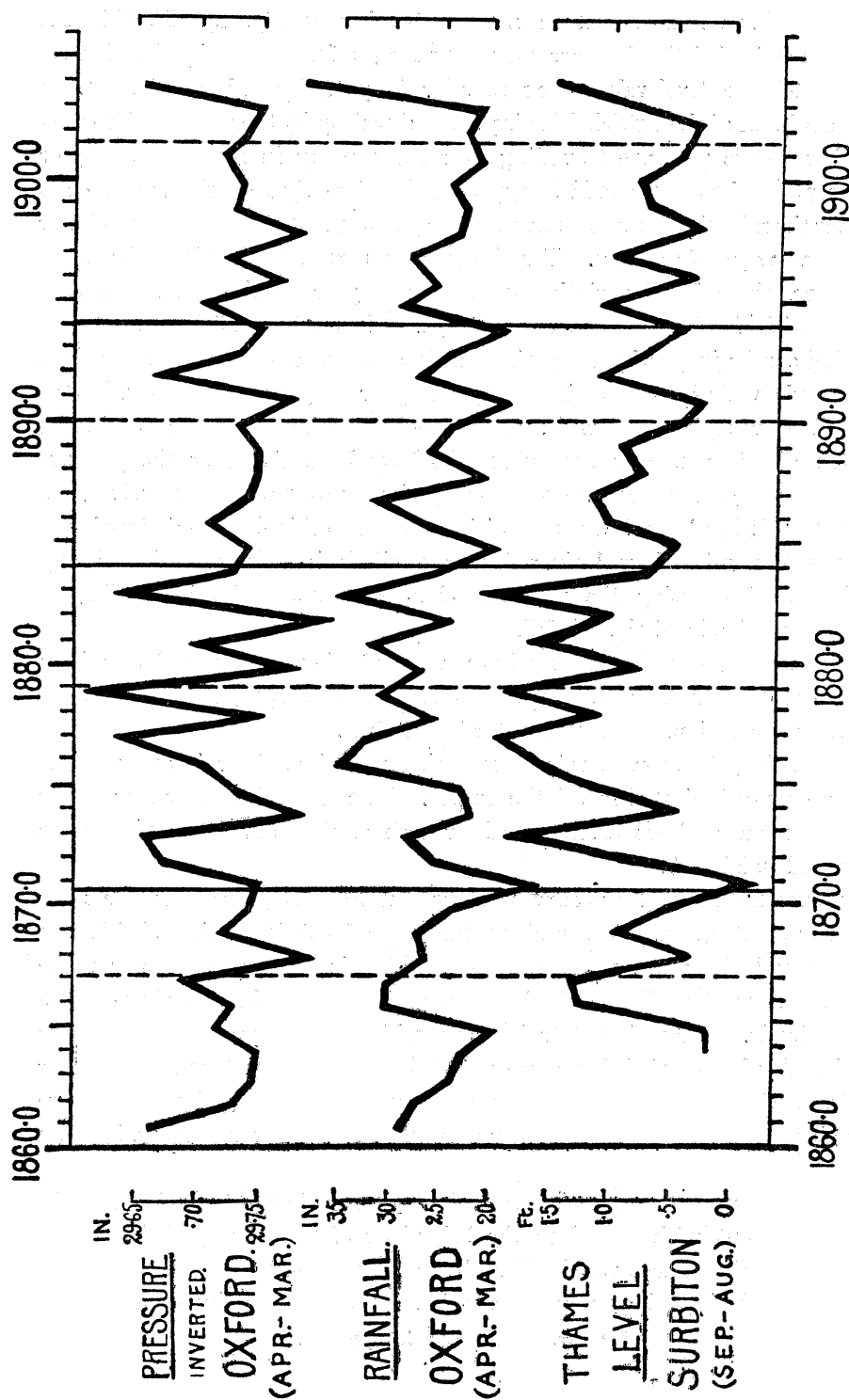


Fig. 2.—Oxford Rainfall and Pressure Changes in relation to Thames Level at Surbiton. (Vertical lines as in Plate 6.)

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variations have been added in a separate diagram (fig. 2). In this the pressure and rainfall values are the means for the 12 months April to March, and the Thames level values the means for the year September to August.

The rainfall of the British Isles is produced mainly by the passage of areas of low barometric pressure travelling over the country in a north-easterly or easterly direction. It should be expected therefore that on the average the greater the rainfall the more numerous the cyclones, and consequently the lower the mean value of pressure. For the greater part of the United Kingdom, therefore, the rainfall variation from year to year should correspond very closely with the inverted pressure change. That this condition is actually fulfilled can be judged by comparing in Plate 6, Curve VIII, representing the barometric variation (curve inverted) from year to year at Oxford with the rainfall curves given below it. Instead of Oxford, any other town in the United Kingdom such as Armagh, might have been given, for the pressure changes from year to year are remarkably similar over a very extensive area. So far then it has been shown that with reference to this short-period variation the pressure, rainfall, and river flow are all intimately related, and any method of forecasting the pressure changes would make it possible to determine beforehand the rainfall.

Since the Thames flow values have a lag of about five months on both rainfall and pressure, a means is possibly available of stating the expectancy of excessive or deficient amount of water in the river.

In addition, however, to this short-period variation, there is an apparent longer change indicated in all the curves. To render the latter more clear three-year means have been formed for each of the curves and the curves re-plotted in Plate 7.

An examination of these curves shows that in those years when the river flow was greatest, *i.e.*, between about the years 1873–1883, the rainfall was highest, and the mean pressure lowest, which is exactly what was to be expected from the relationship between pressure, rainfall, and river-flow in these Islands. The main points, however, which these curves clearly indicate are that this long-period change in each of them is real, and that the low river levels, deficiency of rainfall, and excess pressure of the last series of years are now about to be followed by greater mean flow of the River Thames, increase in the mean rainfall and deficiency of the mean pressure.

In a previous communication, to which reference has already been made, we pointed out with regard to the behaviour of the short-period pressure variations taking place over the Earth's surface that:—*

“In some regions the pressure variation curves were distinctly a mixture

* ‘Roy. Soc. Proc.’ vol. 73, p. 458.

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of both Indian and Cordoba types, and it was difficult to classify them satisfactorily"

One of these regions of mixed-type pressures included Western Europe, comprising the British Isles, Holland, Belgium, France, Spain, Germany, Italy, etc. To illustrate the nature of this British variation in relation to the two main types represented by India and Cordoba (which are the inverse of each other) fig. 3 is added. These curves show the changes of the mean annual values of pressure from year to year, the year being reckoned here from January to December. The uppermost curve represents an hypothetical curve with a period of 3·8 years, and beneath it is given the Cordoba pressure curve. The hypothetical curve was made to fit that of Cordoba as near as possible, and it will be seen that there is very close agreement on the average, with the exception of the years 1892 and 1900 to 1903. At the bottom of the plate is given the *inverse* of the hypothetical curve shown above and the Indian pressure variation curve.*

These two latter curves, also from the year 1873, are in the main very similar, with the exception of the years 1892 and 1901–1903. Previous to 1873 the observed maxima and minima anticipate those of the hypothetical curve.

Between the Cordoba and Bombay curves is placed that of Oxford, representing the barometric changes occurring over the British Isles.

A comparison of these three curves indicates the intermediate nature of the Oxford variation in relation to those of Cordoba and India. The following table gives a statement of the years in which either excessive high or low pressures at Oxford were coincident with corresponding excesses in India or Cordoba :—

Agreement of Oxford with—	Years of simultaneous excess.	
	High pressure.	Low pressure.
Cordoba	1874	—
"	1875	—
"	—	1877
India	—	1878
"	1880	—
"	—	1882
"	1884	—
"	—	1886
Cordoba	1893	—
"	—	1895
India	1896	—
"	1899	—

* It will be noticed that the points of maxima of the hypothetical curve at the top of the plate do not lie midway between the minima on either side of them, but nearer the

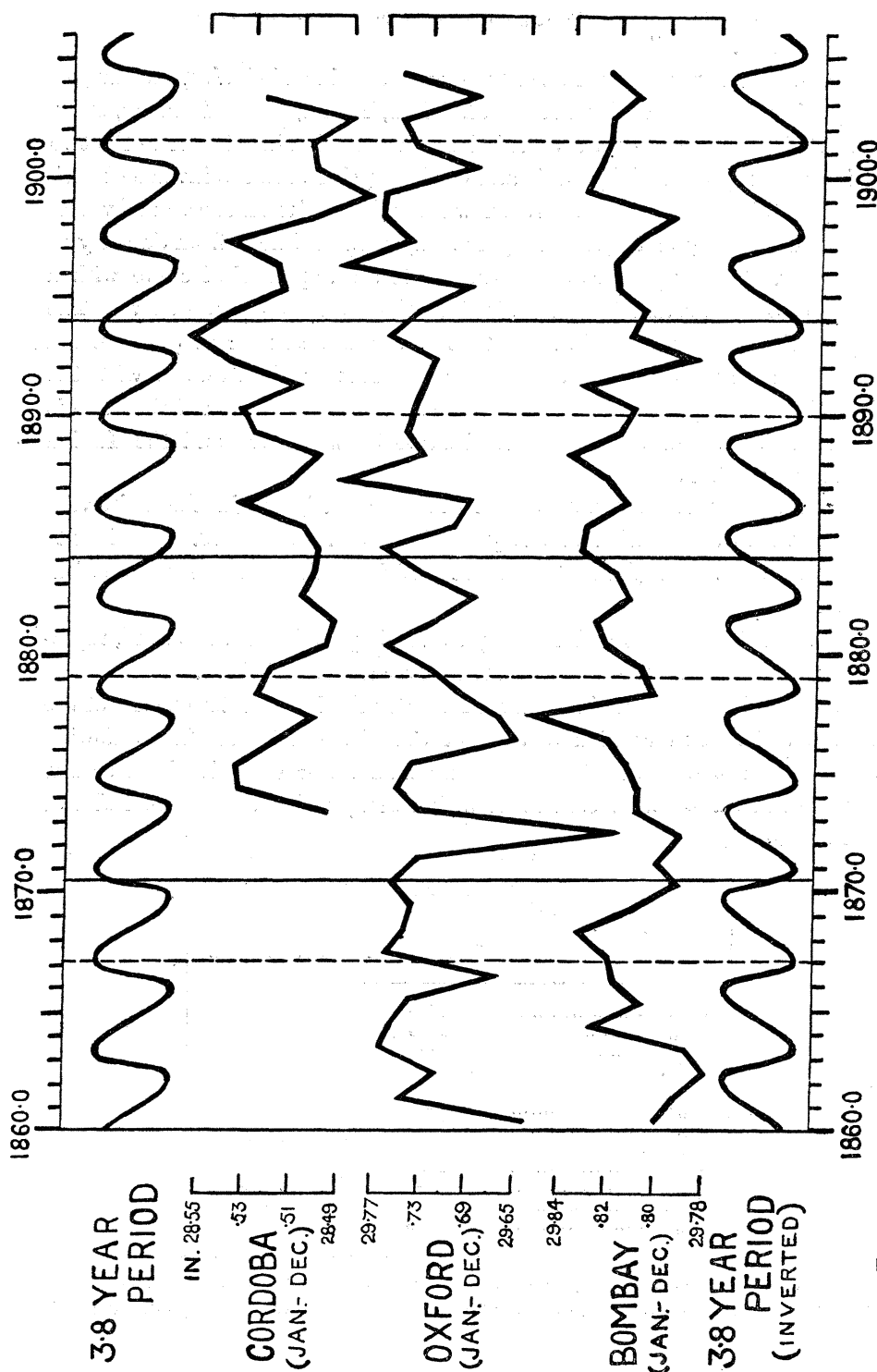


FIG. 3.—British Pressure Change in relation to Indian and S. American Pressure Variations. (Vertical lines as in Plate 6.)

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From this it will be seen that there seems to be a very even balancing between Cordoba and India, the former claiming coincidences with Oxford of three excess highs and two lows, while the latter has four excess highs and three lows.

An interesting point which the above table clearly brings out is that the Oxford curve seems to favour for series of years the two main pressure types *alternately*. Thus, from 1874 to 1877 the curve more resembles Cordoba, from 1878 to 1887, India; from 1888 to 1895, Cordoba again, and from 1896 to 1899, India.

From 1900, as far as observations are available, the type of variation is indefinite.

It is possible that it is this alternate reversion from one type to the other that prevents the 3·8 year change of the Indian and Cordoba curves from occurring in the British curves, and substitutes for it an apparent shorter period of about three years, which is very noticeable in all the British curves shown in Plate 6.*

A closer study then of the British pressure changes in relation to those of the Indian and Cordoba regions may, therefore, throw considerable light on the pressure changes occurring in these islands.

With regard to the long-period changes which are taking place in the British Isles, the subject will not be referred to here at any great length as it is still under discussion. There is, however, sufficient evidence to show that this British variation is different in length of period from that in action in the Indian region, while the latter is again different from the long-period changes occurring in the Cordoba region. This inquiry is one of great interest, but lack of sufficient data has delayed the completion of the investigation. It is hoped, however, soon to communicate the results when these requirements have been fulfilled.

The curves in Plate 7 give a general idea of the long-period British variation that is in progress, and there seems evidence that the minimum of this change has already passed. As the length of this period is about 35 years, and the last maximum occurred in the years about 1878, the curves should now all rise until about the year 1913, when the next maximum may be expected. On the average, therefore, during the next decade

preceding minimum. The curve was drawn in this manner because it was found that, when a symmetrical curve was inverted, it did not correspond well with the Indian pressure curve, while an unsymmetrical one, as shown, made a better agreement.

* Previous to the year 1879 this hypothetical three-year curve begins to disagree with the actual observed values, the maxima and minima of the latter anticipating those of the hypothetical curve. A similar kind of disagreement was also noticed in the curve of Indian pressure changes (previous to 1873) and the 3·8 hypothetical curve.

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pressure should decrease, rainfall should increase, and the Thames flow become greater.

In addition to those to whom reference has already been made, we wish to express our thanks to Messrs. W. Moss and T. F. Connolly for assistance in the computations and drawing of the curves.

Conclusions.

The above discussion indicates that the following deductions may be made :—

1. The Thames flow has a lag of about five months on the rainfall occurring in the Thames Basin.
 2. The flow is closely associated with the rainfall of this basin.
 3. The rainfall variations of the Thames Basin are identical with those of the larger portion of Great Britain, more particularly the eastern regions.
 4. These rainfall changes vary inversely with the pressure changes that occur over the whole of the British Isles.
 5. The British pressure variation is closely associated with the barometric see-saw occurring between the Indian and South American regions.
 6. For all practical purposes the pressure and rainfall data of one station, namely, the Radcliffe Observatory, Oxford, are sufficient to indicate very closely the subsequent changes in the Thames flow.
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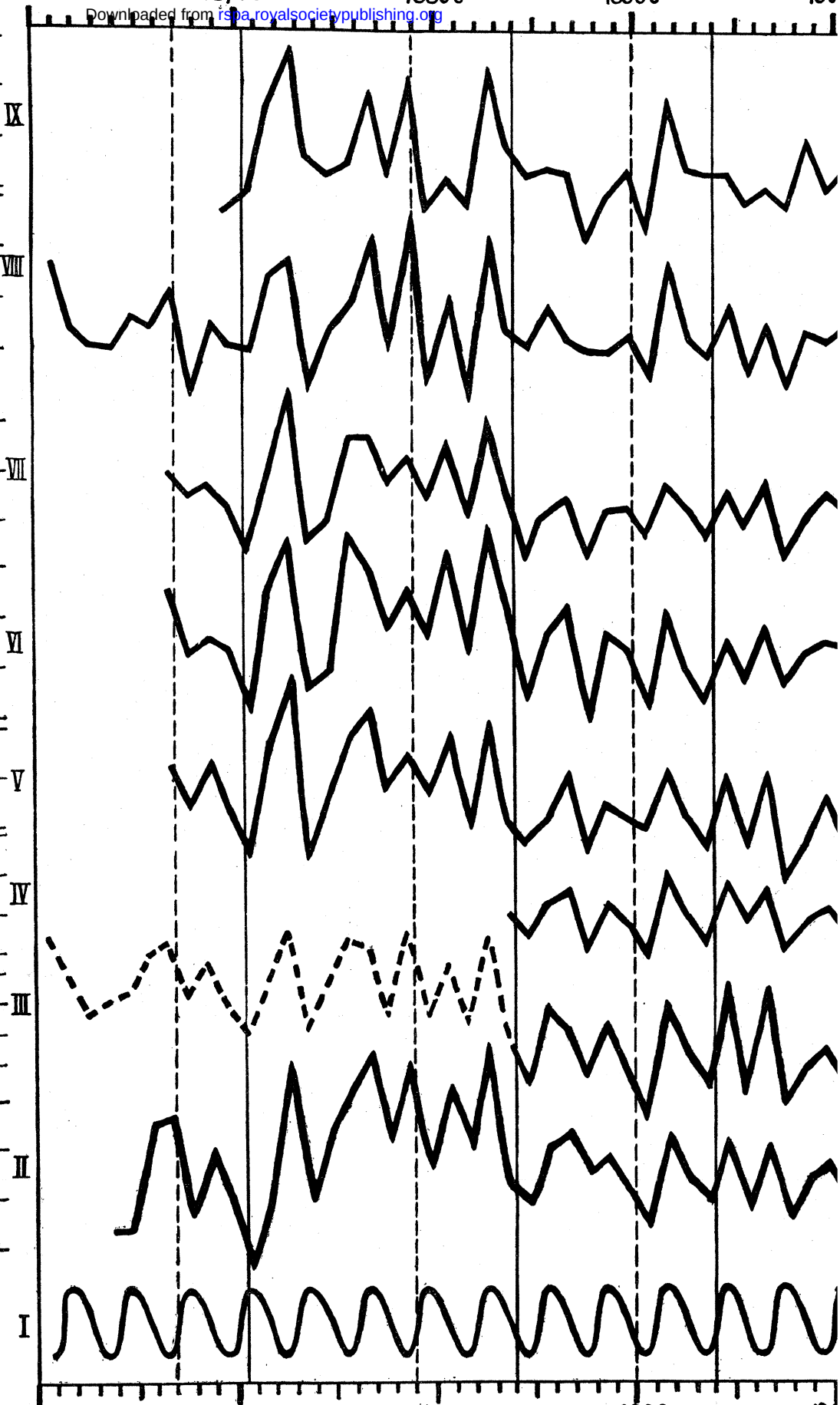
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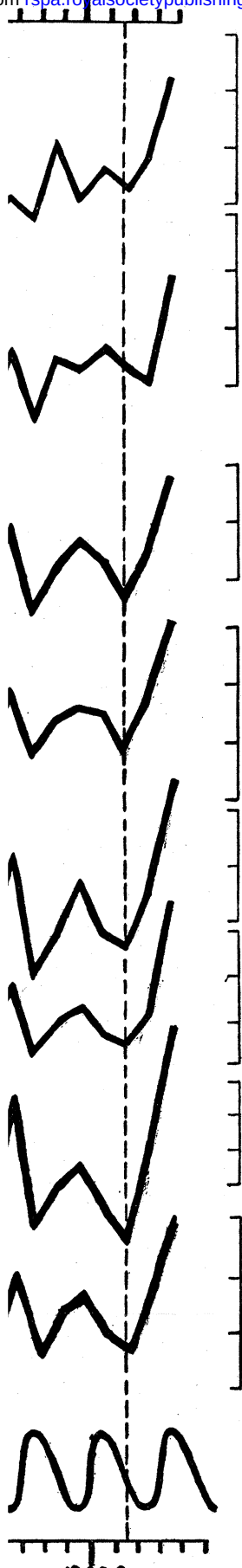
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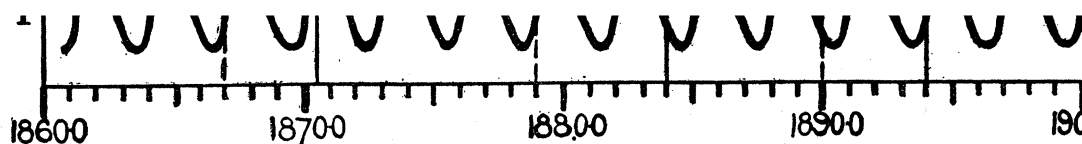


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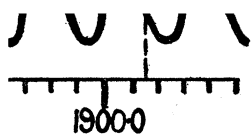
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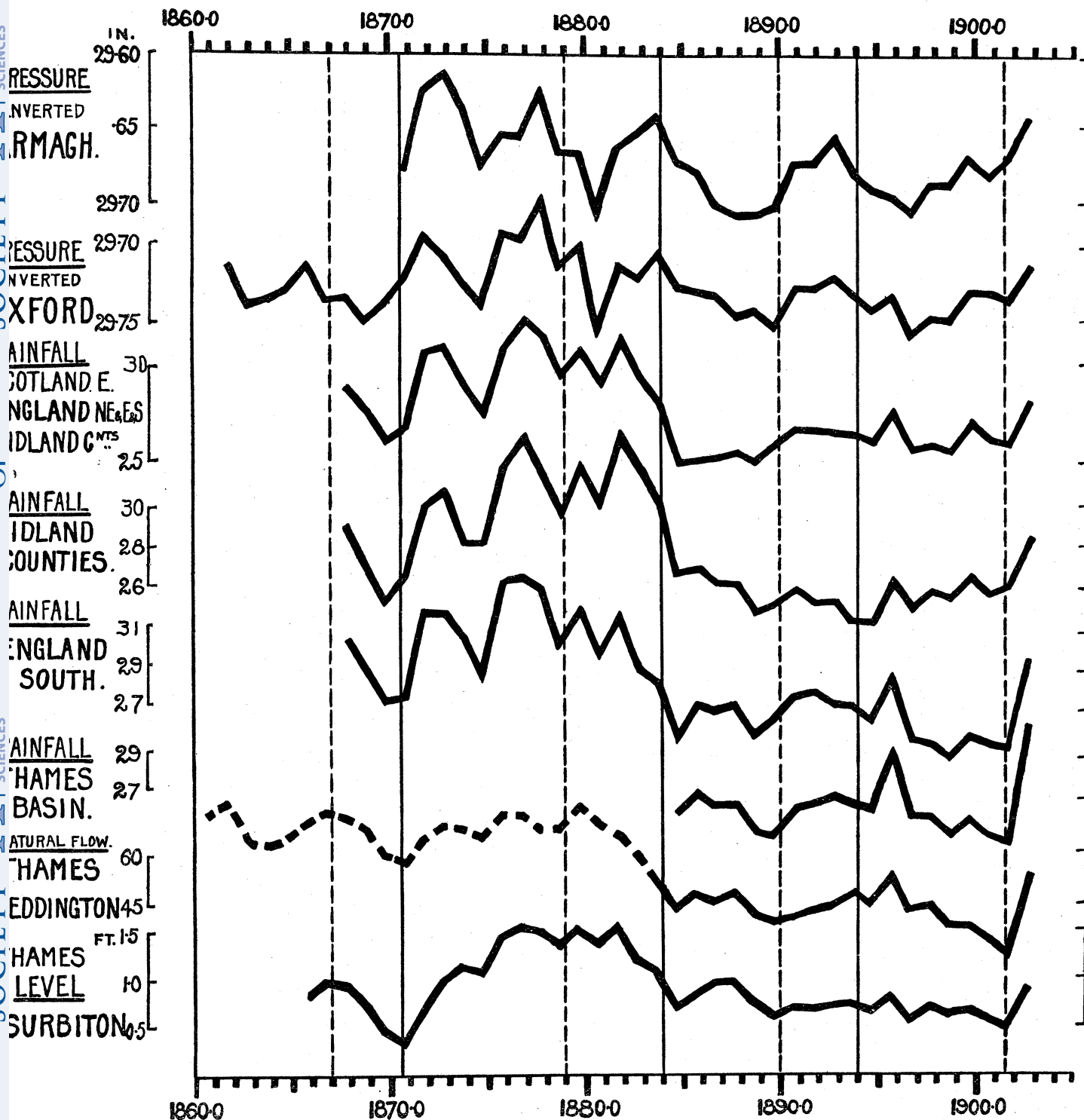
ves to illustrate the Similarity between the Short-period Changes of Pressure (curves inverted) and Thames Flow, in the British Isles. (The continuous and broken vertical lines represent sunspot maxima and minima, as determined from the mean daily areas of both hemispheres)



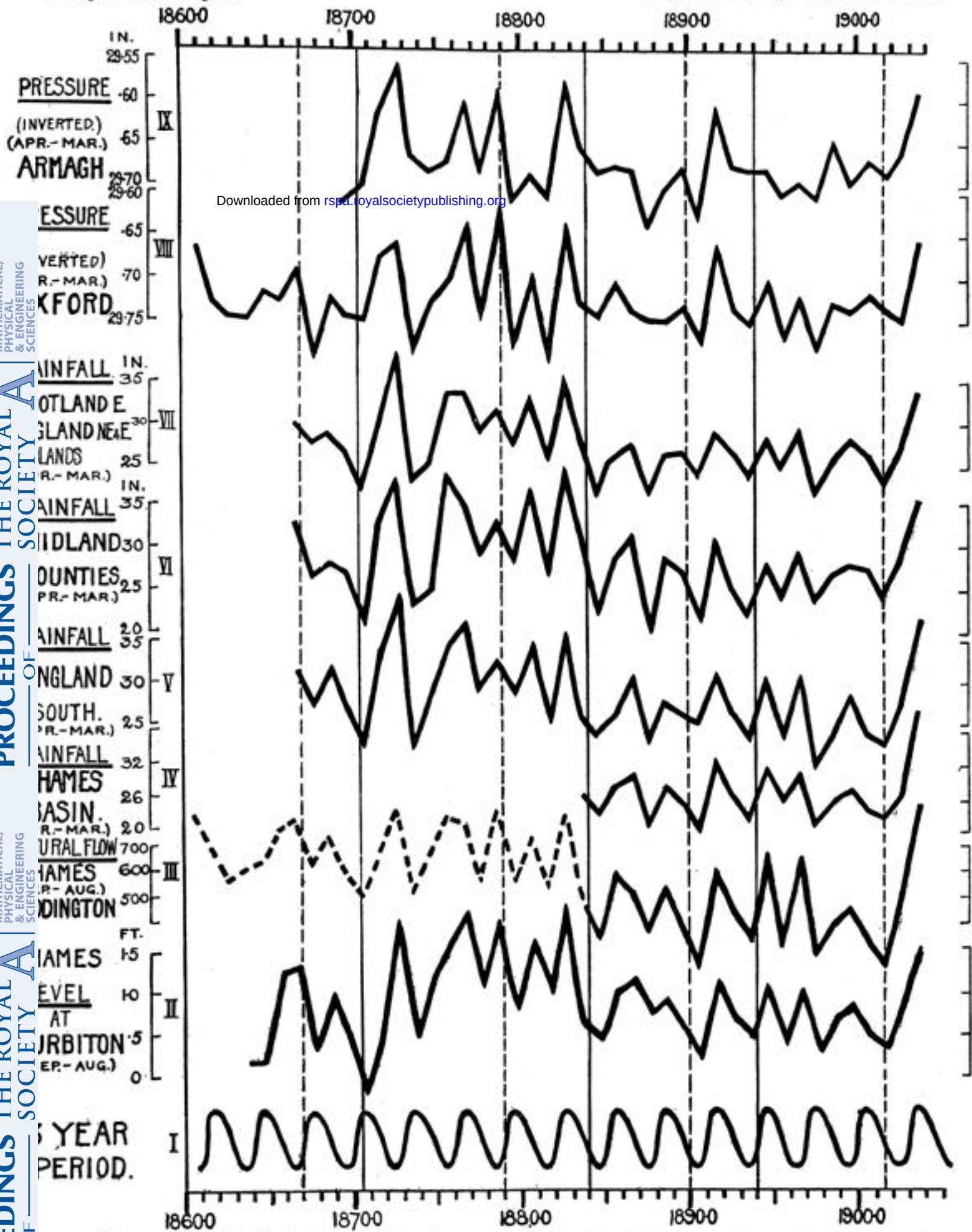
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Roy. Soc. Proc., vol. 76A, Plate 7.



curves to illustrate the Similarity between the Long-period Changes of Pressure (curves inverted), Rainfall, and Thames Flow, in the British Isles. (Vertical lines as in Plate 6.)



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Figures to illustrate the Similarity between the Short-period Changes of Pressure (curves inverted), Rainfall, and Thames Flow, in the British Isles. (The continuous and broken vertical lines represent the epochs of sunspot maxima and minima, as determined from the mean daily areas of both hemispheres of the sun.)